

LEAN STABILITY AUGMENTATION STUDY

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An analytical and experimental program was conducted to investigate techniques and develop technology for improving the lean combustion limits of premixing, pre-vaporizing combustors applicable to gas turbine engine main burners. In the analytical conceptual design study, three concepts for improving lean stability limits were selected for experimental evaluation among twelve approaches considered. Concepts were selected on the basis of the potential for improving stability limits and achieving emission goals, the technological risks associated with development of practical burners employing the concepts, and the penalties to airline direct operating costs resulting from decreased combustor performance, increased engine cost, increased maintenance cost and increased engine weight associated with implementation of the concepts. Tests of flameholders embodying the selected concepts were conducted in an axi-symmetric flametube test rig having a nominal diameter of 10.2 cm at a pressure of 10 atm and at a range of entrance temperatures simulating conditions to be encountered during stratospheric cruise. A total of sixteen test configurations were examined in which lean blowout limits, pollutant emission characteristics, and combustor performance were documented.

The use of hot gas pilots, catalyzed flameholder elements, and heat recirculation to augment lean stability limits was considered in the conceptual design study. On the basis of the results of the study, three classes of augmented flameholders were designed and tested. The first class involved the use of cavities or recesses located in the downstream face of a perforated plate flameholder--these configurations are referred to as Self-Piloting Recessed Perforated Plates. The second class involved the use of tube bundles wherein the inner diameter of the tubes and/or the rearface of the tube array was treated with a platinum/rhodium catalyst. These configurations were referred to as Catalyzed Tube Flameholders. The third class of flameholders involved the direct injection of gaseous or liquid fuel into the recirculation regions formed behind V-gutter or perforated plate flameholders. This class of flameholders is referred to as Piloted Flameholders. The primary goal of the program was to achieve stable operation of the combustors at equivalence ratios as low as 0.25. It was desired that the NO_x emission index be less than 1.0 g/kg at the design conditions ($T_0 = 600 \text{ K}$, $\phi = 0.6$). It was also desired that the combustor operate efficiently over a range of entrance temperatures from 600 to 800 K, a range of equivalence ratios from 0.3 to 0.6, and that the maximum emission of nitric oxides be less than that corresponding to an emission index of 3.0 g/kg.

The most promising configuration identified in this program involved the injection of pilot fuel into the base or recirculation region of a bluff-body flameholder. It was determined that with a pilot fuel flow equal to 5 percent of the total fuel flow at the design conditions, combustor blowout did not occur as fuel flow was decreased to levels corresponding to an overall equivalence ratio of 0.25. For this configuration, the NO_x emission index at the design point was less than half of the design goal and, at off-design conditions, the maximum NO_x emission index goal was exceeded only for the $T_0 = 800 \text{ K}$, $\phi = 0.6$ case. At the lower entrance temperature conditions tested ($T_0 = 700$ and 600 K), the measured combustion efficiencies were unacceptably low and further effort is required to obtain the desired performance. No substantial improvement in blowout limits was achieved for the self-piloting recessed perforated plate configurations or the catalyzed tube configurations.

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NASA Lean Stability Augmentation Study

- **Objective : Attainment of improved lean blowout limits**

- **Tasks : I Conceptual design study**
 - II Experimental design**
 - III Fabrication and installation**
 - IV Combustor tests**
 - V Final design and test**
 - VI Reports and records**

Program Goals

Conditions:

$$P = 10 \text{ atm}$$

$$\underline{600} \leq T_i \leq 800 \text{ K}$$

$$0.25 \leq \phi_p \leq \underline{0.6}$$

$$V_{\text{ref}} = 25 \text{ m/sec}$$

Emissions:

$$EI_{\text{NO}_x} < 1.0 \text{ at design; } < 3.0 \text{ overall}$$

$$EI_{\text{CO}} < 10.0 \text{ at design}$$

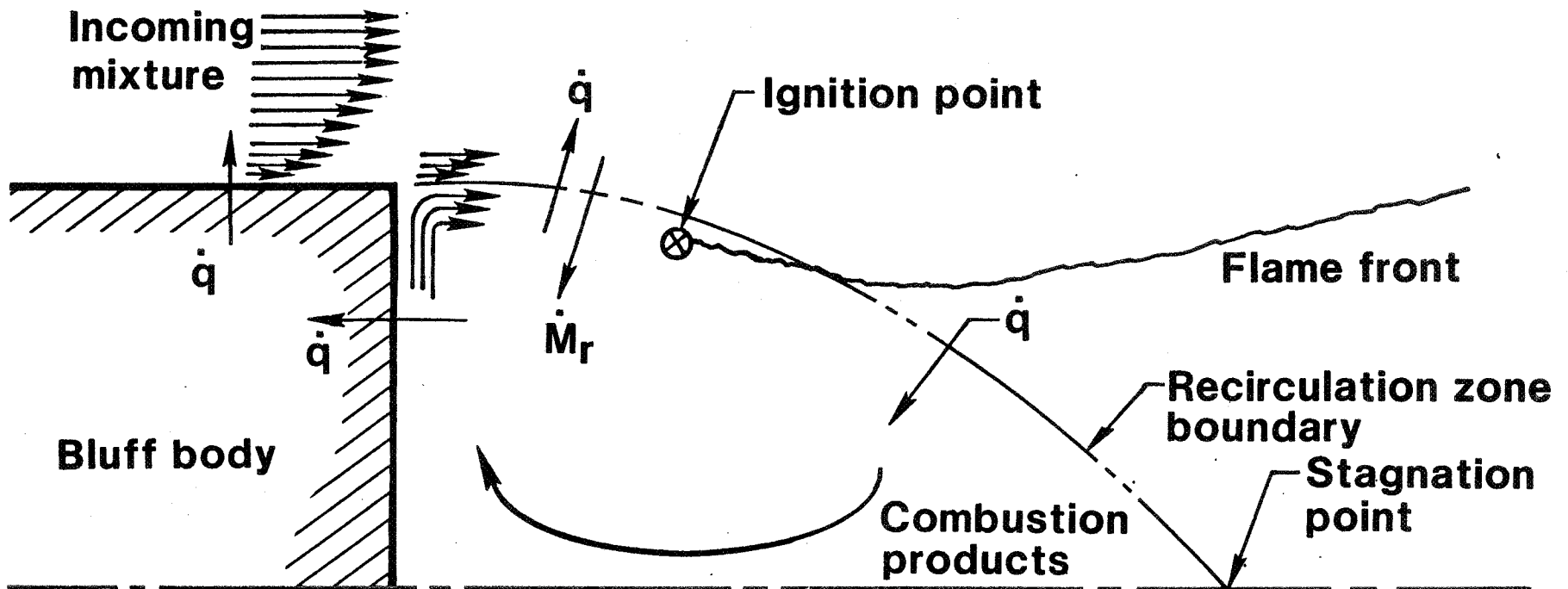
$$EI_{\text{UHC}} < 1.0 \text{ at design}$$

Performance:

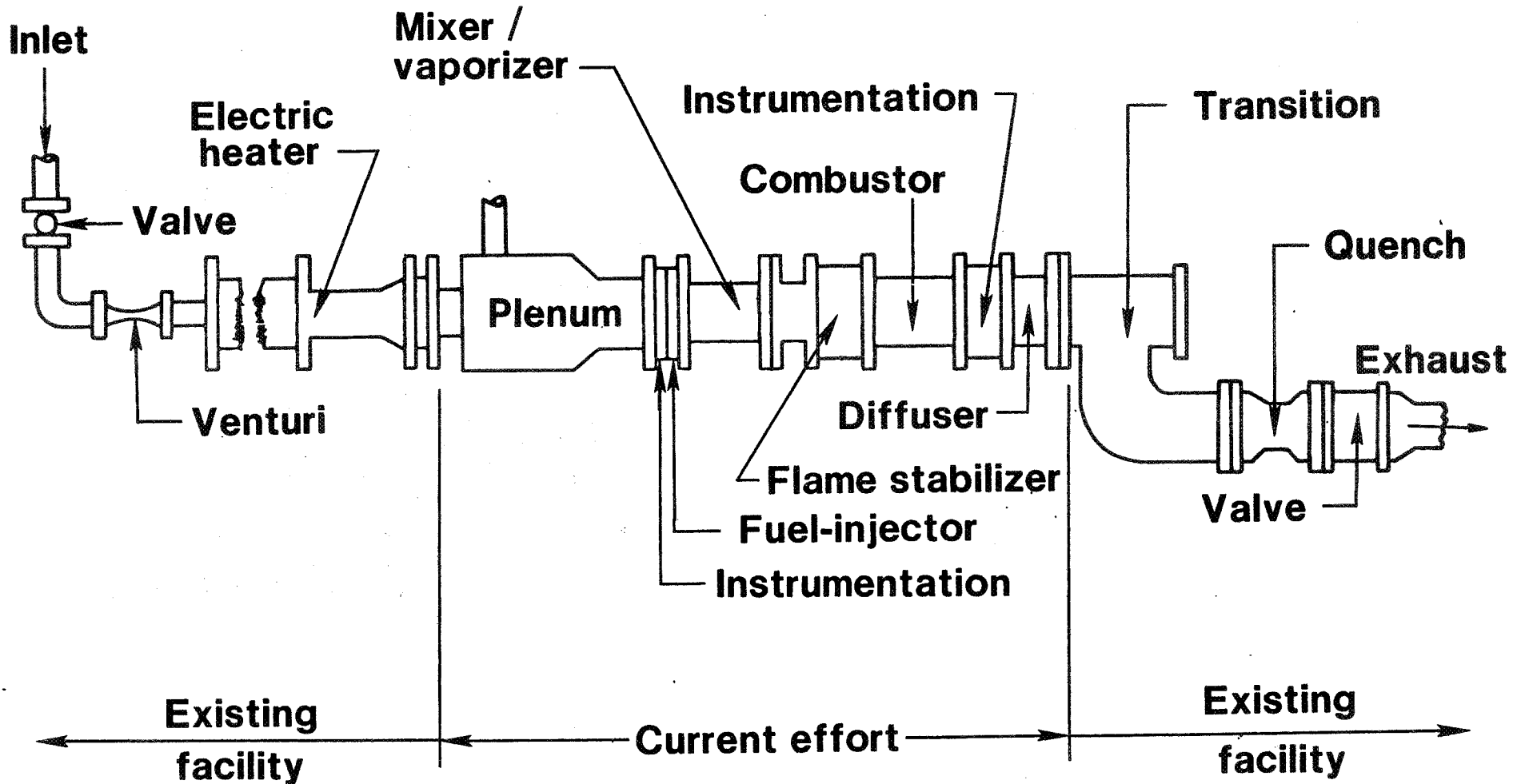
$$\eta_{\text{comb.}} \geq 0.99 \text{ for } 0.3 \leq \phi \leq 0.6$$

$$\Delta P / P < 0.05$$

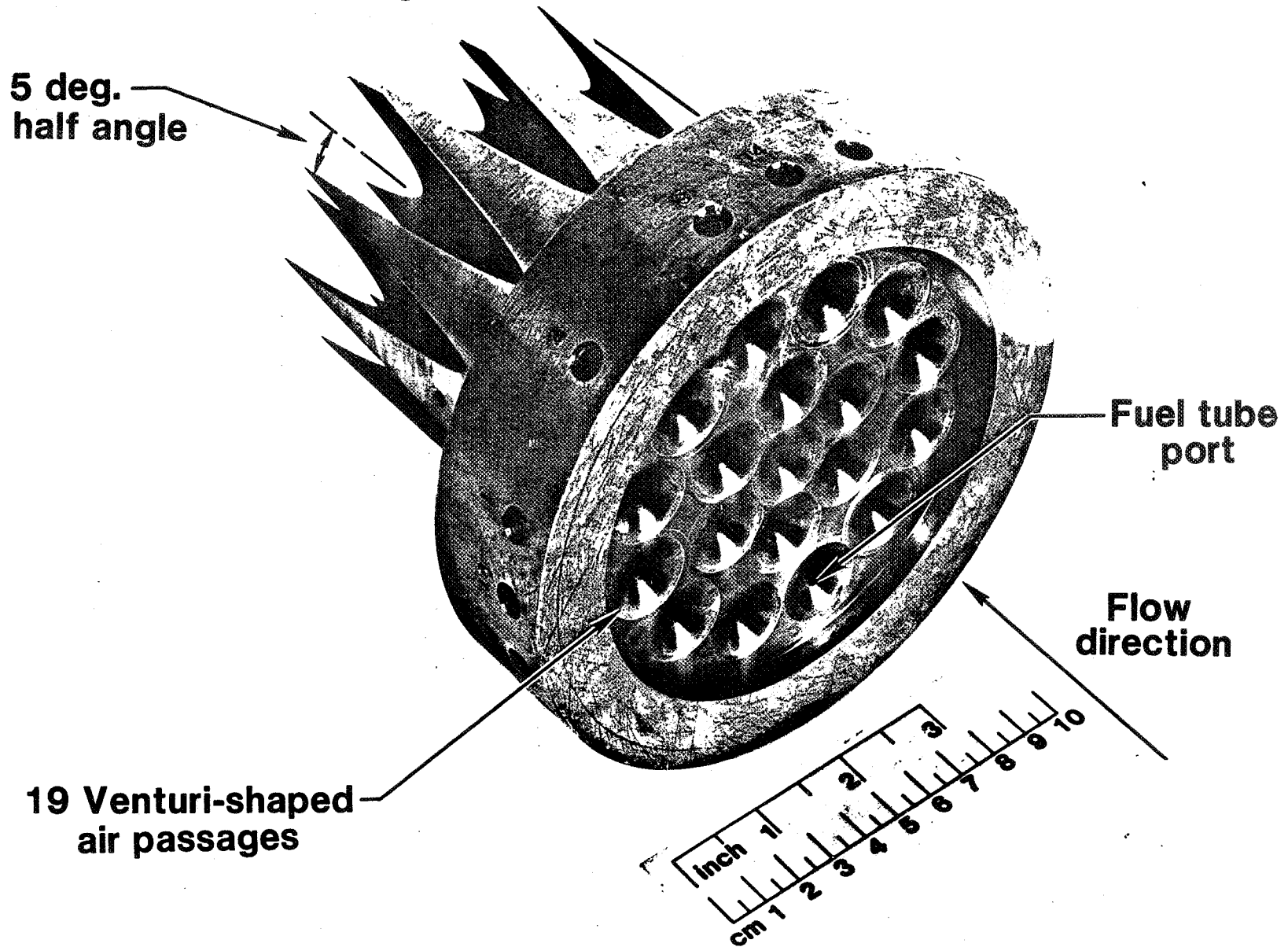
Bluff Body Flame Stabilization Process



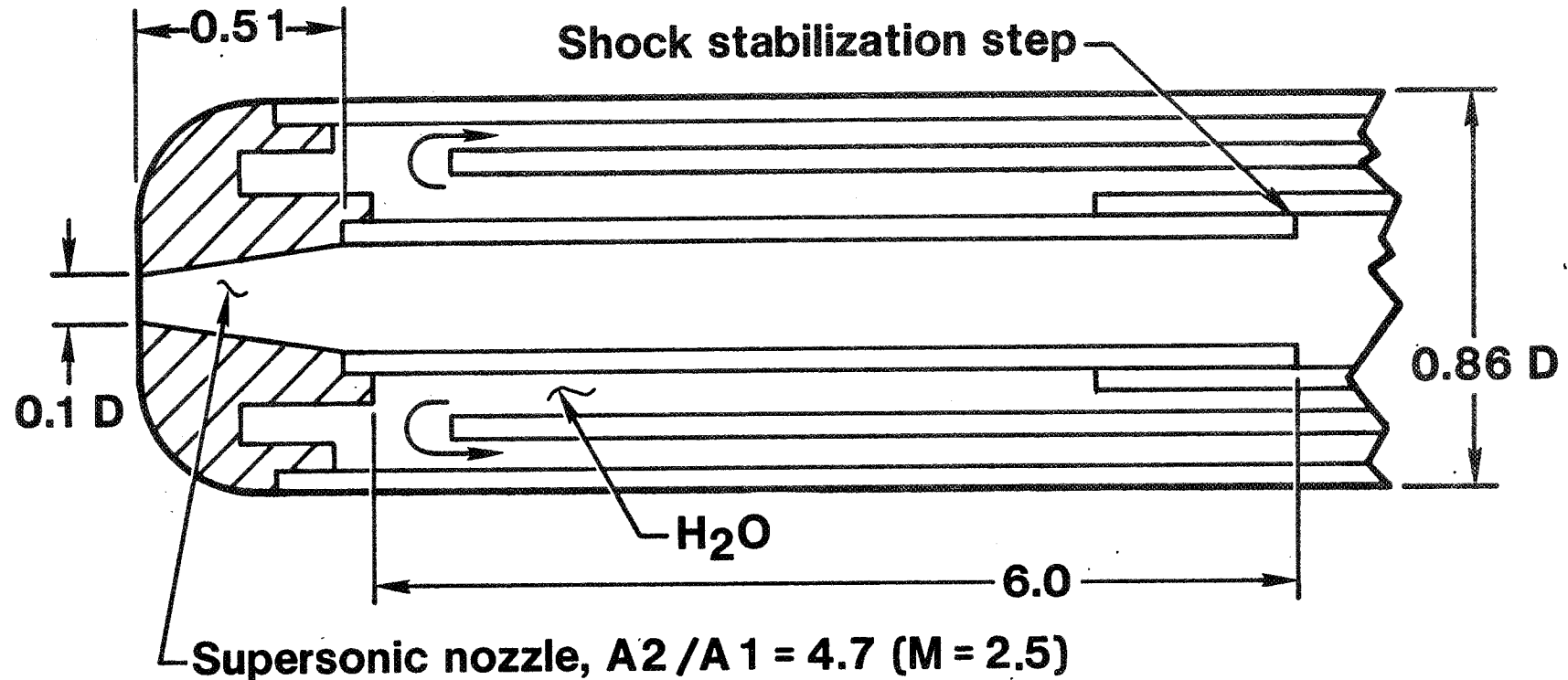
Lean Stability Augmentation Study Test Facility



Fuel Injector – Airflow Nozzle



Emission - Probe Tip Construction



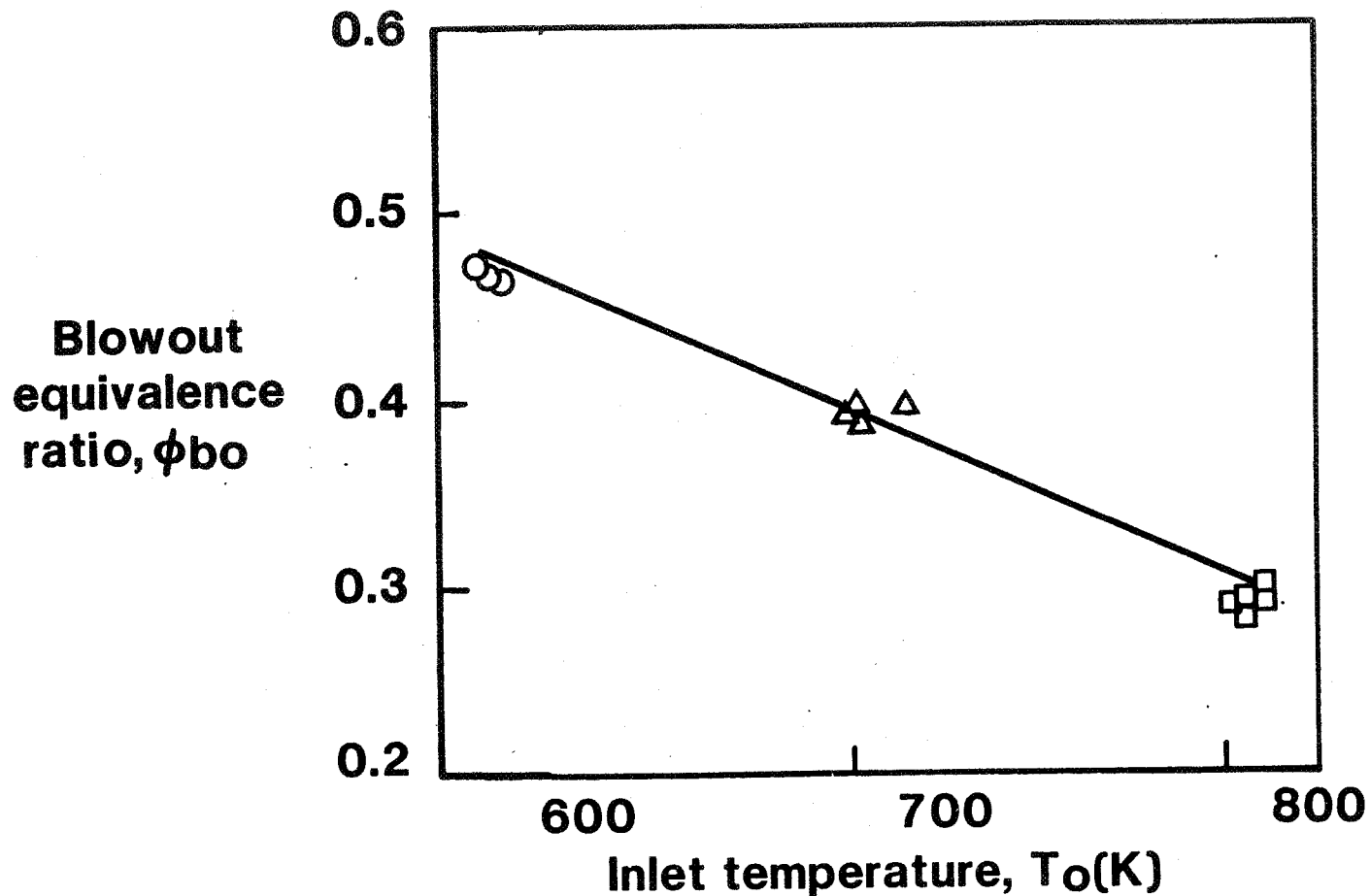
Note: All dimensions in cm

Baseline Flameholder Blowout Limits

75% blockage perforated plate

$(\Delta P/P_T)_{\text{cold}} = 2.3\%$

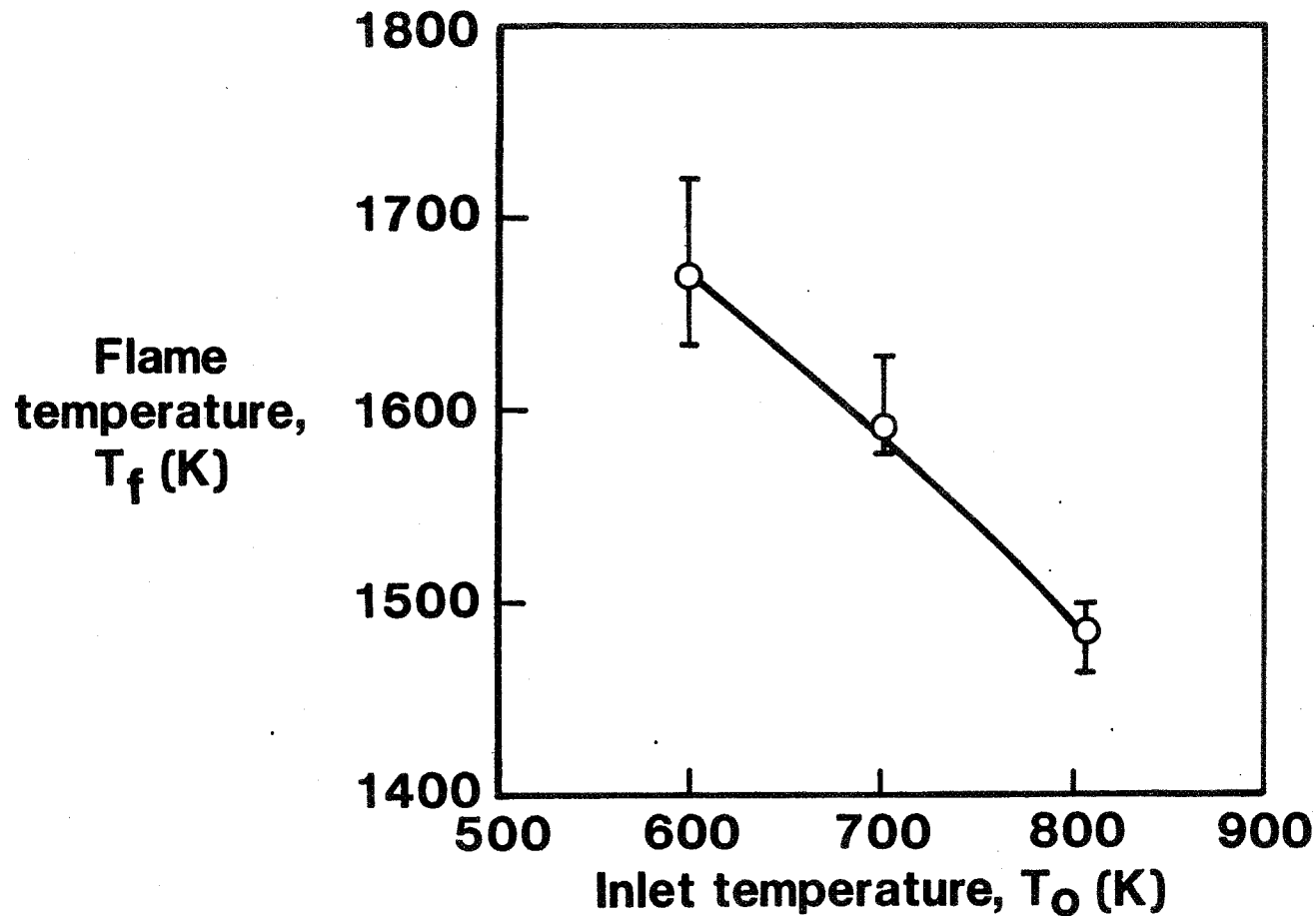
$P = 10 \text{ atm}$



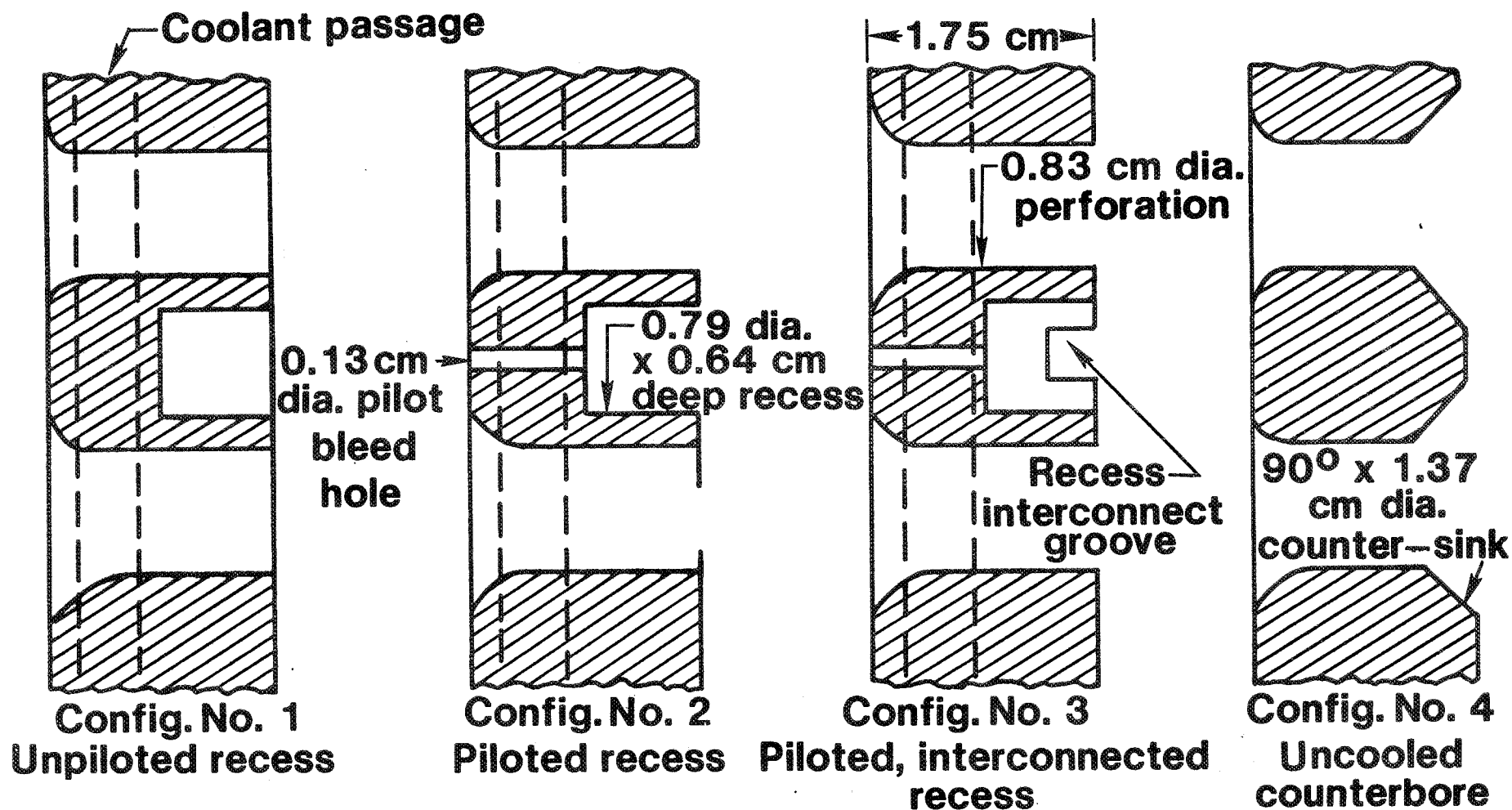
Variation of Blowout Flame Temperature with Inlet Temperature

Baseline configuration

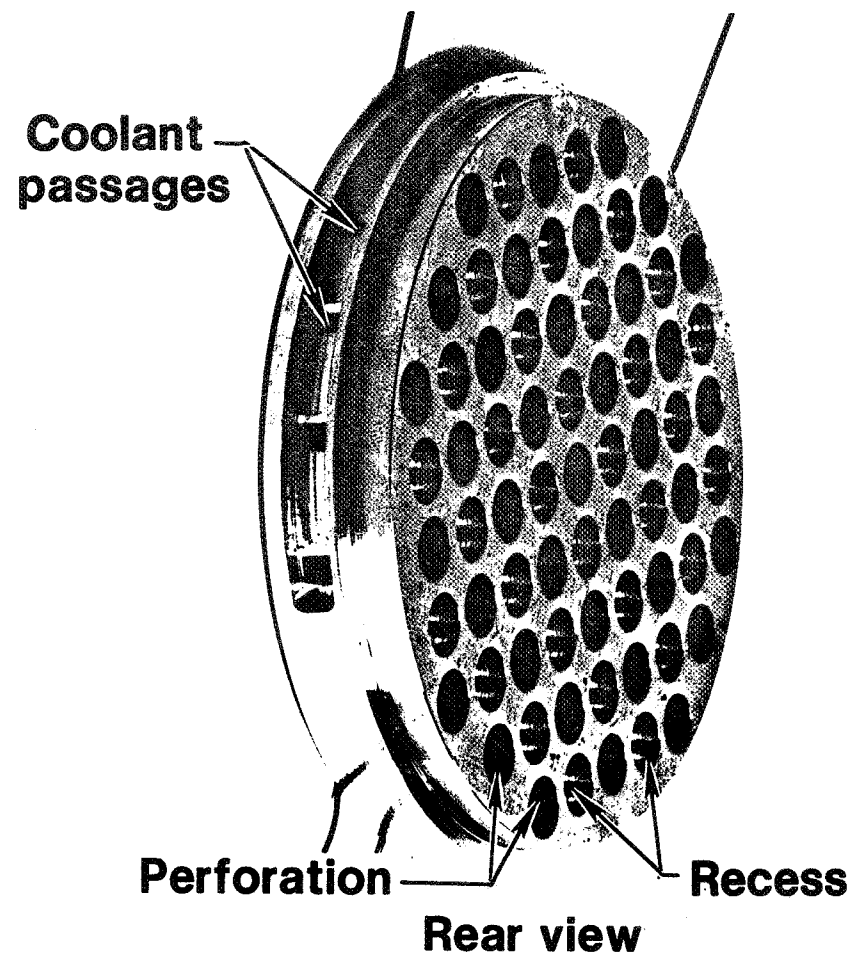
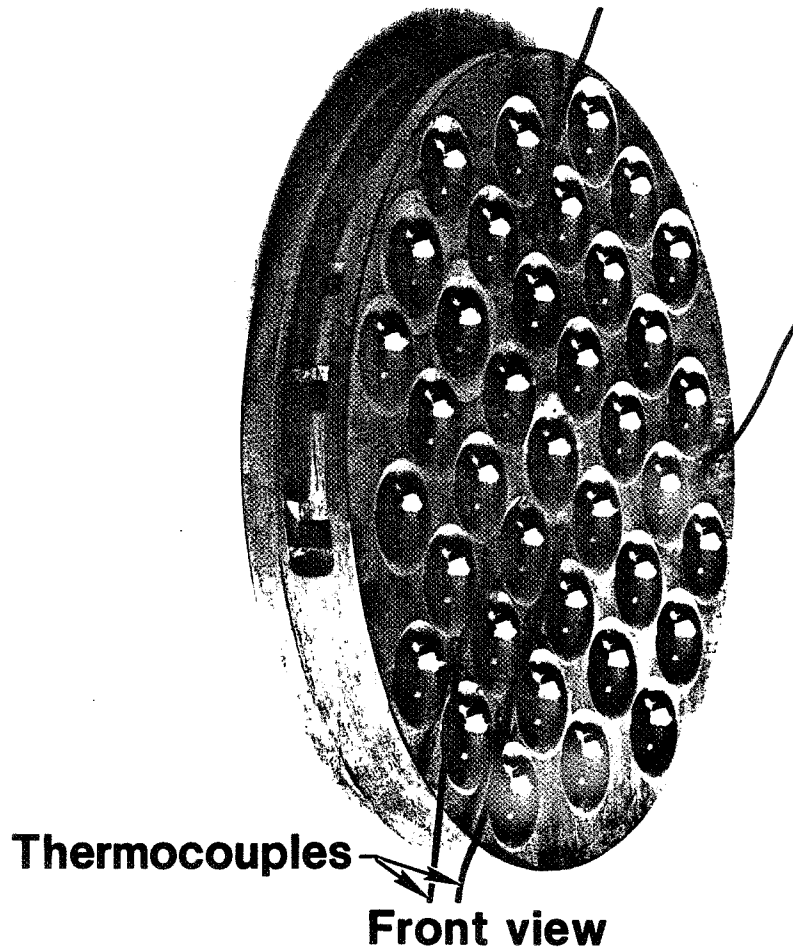
$P=10$ atm



Self-piloting Recessed Perforated Plate Flameholders



Recessed Self-piloting Perforated Plate Flameholder

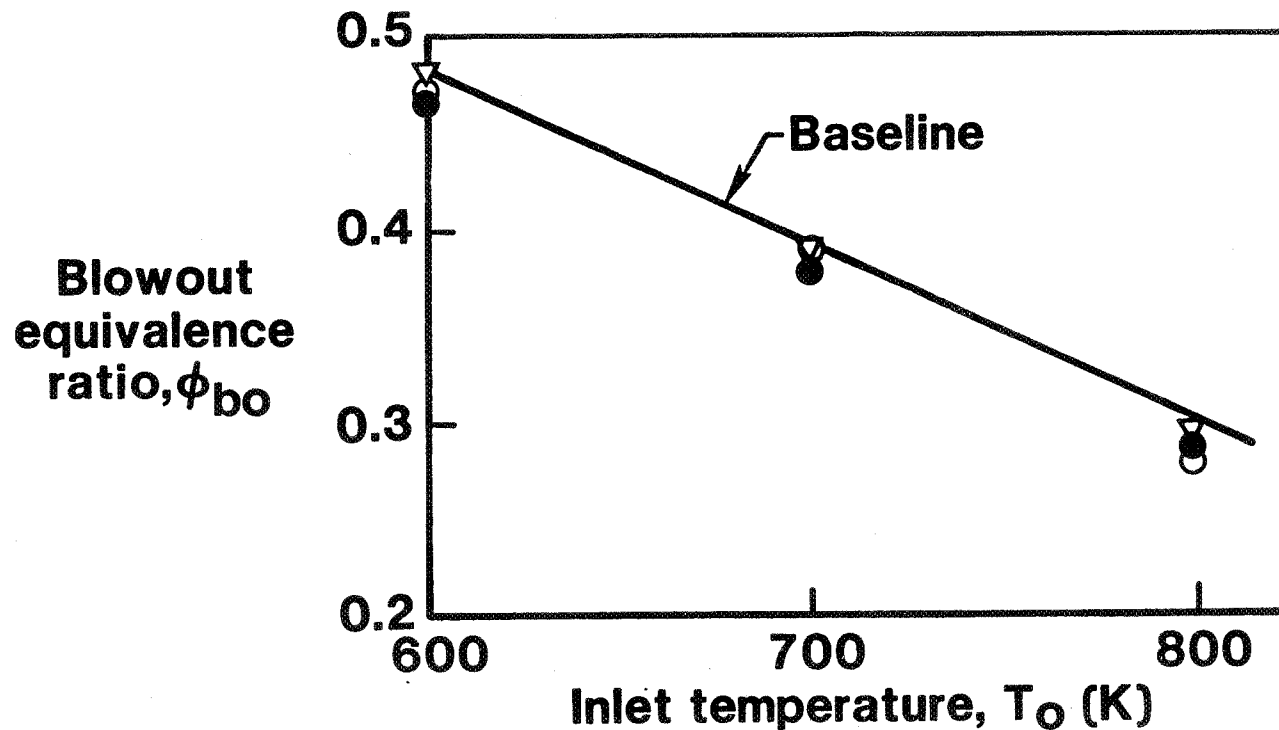


Lean Stability Limits

Self-Piloting Recessed Perforated Plate Series

Configuration

- Recess only
- Recess + pilot
- △ Interconnected recesses + pilot
- ▽ Countersink
- Final 80% blk; deep counter bore



Self-Piloting Recessed Perforated Plate Final Design

Note: All dimensions in cm
80% blockage

